# Human Sustainability

*Focus: Solar Energy*

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**Unit Plan**

*Geoscience/Geoscience H*

Grade Band: 10-12 Topic: Human Sustainability

## Brief Lesson Description

Students will investigate the science behind solar energy then use the engineering design process to create a solar thermal water heater.

## Performance Expectation(s)

1. HS-ESS2-4. Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.
    a. ESS2. D. The foundation for Earth's global climate systems is the electromagnetic radiation from the Sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space.
2. HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.
    a. ETS1. B When evaluating solutions, it is important to consider a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.
3. HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
4. HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

## Knowledge Targets

1. Students can use or create a model to show the flow of energy once it has reached Earth's surface.
2. Students can describe how various factors or events can affect the flow of energy into and out of Earth's systems.
3. Students can describe the natural systems being affected by human activity and explain how they are being affected.
4. Students can describe and quantify criteria and constraints, as well as tradeoffs, for solutions to reduce impacts of human activities on natural systems.
5. Students can hypothesize the impact a proposed solution could have on society and the environment.
6. Students can evaluate or refine a technological solution to reducing human activities on natural systems based on scientific knowledge and reasoning.
7. Students can evaluate the effect of a proposed solution and make refinements.

## Performance Targets

1. Students can use evidence to identify a problem as a major global challenge.
2. Students can identify qualitative and quantitative criteria and constraints when proposing solutions to a problem.
3. Students can consider different societal needs when addressing a potential solution to a global challenge.
4. Students can identify boundaries to clarify what is or is not part of the problem being addressed.
5. Students can use evidence to analyze criteria and systematically evaluate each component of a proposed solution using a matrix.
6. Students can provide evidence as to how possible solutions optimally address the criteria and constraints of the problem.

7. Students can hypothesize the impact a proposed solution could have on society and the environment.
8. Students can identify which parts of the complex real-world problem may remain if the proposed solution is implemented.

| Science & Engineering | Disciplinary Core Ideas | Crosscutting Concepts |
|---|---|---|
| *Developing and Using Models*<br>• Use a model to provide mechanistic accounting of phenomena.<br>*Asking Questions and Defining Problems*<br>• Analyze complex real-world problems by specifying criteria and constraints for successful solutions.<br>*Constructing Explanations and Designing Solutions*<br>• Design or refine a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. | *ESS2.D Weather and Climate*<br>• The foundation for Earth's global climate systems is the electromagnetic radiation from the Sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land, systems, and this energy's re-radiation into space.<br>• Changes in the atmosphere due to human activity have increases carbon dioxide concentrations and thus affect climate. | *Cause and Effect*<br>• Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. |

## Unit Plan

Written for students to work in teams of six on a 90-minute block schedule.

**Day 1: Greenhouse Effect**

- Materials
  a. Computer
  b. Pen/pencil
  c. Web Quest: Greenhouse Effect
- Procedure
  1. Have student work through the Web Quest about the greenhouse effect.
  2. Review answer at the end of class.

**Day 2 and 3: A Closer Look at Solar Energy**

- Materials
  a. Computer
  b. Pen/pencil
  c. Butcher paper (or other potential mediums)
  d. Markers
  e. Video: Climate Change-Earth's Giant Game of Tetris
  f. Video Quiz
- Procedure
  1. Ask teams to watch *Climate Change-Earth's Giant Game of Tetris* https://ed.ted.com/lessons/climate-change-earth-s-giant-game-of-tetris-joss-fong then answer video quiz questions. When teams are finished, ask them to share their answers with the rest of the class.
  2. Next, ask the class to name a renewable, technological solution that reduces the impact of human activities on the Earth system.
  3. After students say, "solar energy" assign each team one of the following constraints to research: cost, aesthetics, reliability, social, cultural, or environmental impacts of using solar energy. Ask teams to type their answers to

the analysis questions then summarize their findings on a piece of butcher paper or other medium. Teams will present their findings during the next class period.

**Day 4, 5, 6, 7: Designing a Solar Thermal Water Heater**

- Materials
    a. Solar Thermal Water Heater Kit
    b. Appendix A
    c. Thinking Critically: Material Properties
    d. Activity: Designing a Solar Thermal Collector
    e. Activity: Solar Thermal Water Heater
    f. Thinking Critically: Solar Energy
    g. Video: Sol Traveler Introduction, Sol Traveler: Assembly
    h. Activity: Identifying Criteria and Constraints
    i. Graph paper
    j. Pen/pencil
    k. Computer
    l. Calculator
    m. Periodic table
    n. Pegboard
    o. Scissors
    p. Blue painters tape
    q. Foil
    r. Black tubing
    s. White tubing
    t. Copper tubing
    u. Zip ties
    v. Trash bag (white, black)
    w. Plastic wrap
- Procedure
    1. First, build the solar thermal water heater.
    2. Next, as a class read *Thinking Critically: Fundamentals of Solar Energy* https://www.nationalgeographic.org/encyclopedia/solar-energy/ then answer the questions that follow.
    3. Now, distribute *Activity: Solar Thermal Water Heater*. Demonstrate how the solar thermal water heater works. You may want to show the *Sol Traveler: Introduction* and *Sol Traveler: Assembly* at https://solarnexus.epscorspo.nevada.edu/sol-traveler/4.
    4. Show teams how to collect temperature data, calculate flow rate, and create a graph.
    5. Next, ask teams to work through *Thinking Critically: Material Properties*.
    6. Introduce *Activity: Designing a Solar Thermal Collector*.
    7. Help students work through defining the problem and identifying the criteria and constraints. There is a supplemental, teacher led, activity in case this is their first time working through the engineering design process.
    8. Ask students to create individual solutions to the problem.
    9. Ask students to create a criteria rubric then evaluate each team member's design with the help of the evaluation matrix.
    10. Once a design is chosen, ask teams to build then test that design.
    11. Finally, ask teams to optimize their solution.

**Day 8: Summative Assessment**

**Web Quest**
*Greenhouse Effect*

**Question**
How can we learn more about the greenhouse effect?

*Part A*
**Procedure**
Go to https://climatekids.nasa.gov/greenhouse-effect/ then answer the questions that follow.

**Analysis**

1. What is the origin of the term "greenhouse effect"?
____________________________________________________________
____________________________________________________________

1. How does a real greenhouse stay warm even with snow outside?
____________________________________________________________
____________________________________________________________

1. What difference does a jungle make?
____________________________________________________________
____________________________________________________________

1. What difference does an ocean make?
____________________________________________________________
____________________________________________________________

1. What is a cloud?
____________________________________________________________
____________________________________________________________

1. What type of effects do clouds have on the temperature of the Earth?
____________________________________________________________
____________________________________________________________

1. Does the height of the clouds make a difference?
____________________________________________________________
____________________________________________________________

*Part B*
**Procedure**
Go to https://scied.ucar.edu/longcontent/greenhouse-effect then answer the questions that follow.

**Analysis**

1. What are the four major greenhouse gases and their formulas?

___

___

2. What other factors influence the greenhouse effect?

___

___

*Part C*

**Procedure**

Go to https://scied.ucar.edu/earths-energy-balance then answer the questions that follow.

**Analysis**

1. What does albedo mean?

___

___

2. How does the type of Earth surface change the albedo?

___

___

*Part D*

**Procedure**

Go to https://scied.ucar.edu/molecular-vibration-modes then answer the questions that follow.

**Analysis**

1. How do carbon dioxide and other greenhouse gases work to absorb infrared radiation?

___

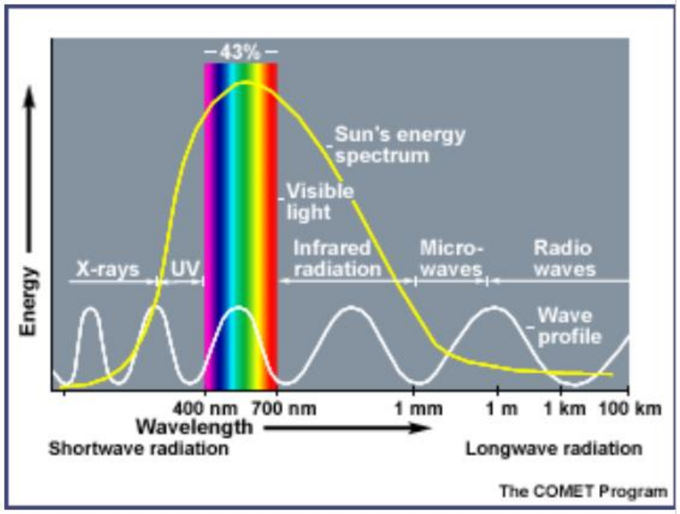
___

2. Why don't nitrogen gas ($N_2$) and oxygen ($O_2$) gas act as greenhouse gases?

___

___

3. Look at the graph about solar radiation. The x-axis of this graph contains the various sizes of radiation of the electromagnetic spectrum (X rays on the left have the smallest wavelength, while Radio waves on the right have the largest wavelength). The Y axis of this graph indicates increased concentration of these types of radiation.




A. What is the size range of a single wavelength of visible light? (nm means nanometer)

______________________________________________________________________

______________________________________________________________________

B. What is the size range of a single wavelength of infrared light?

______________________________________________________________________

______________________________________________________________________

4. The yellow line on this graph indicates the types and concentrations of the radiation released by our Sun.

A. What kinds of radiation does our Sun release? (Hint: Look at the diagram and list the energy types.)

______________________________________________________________________

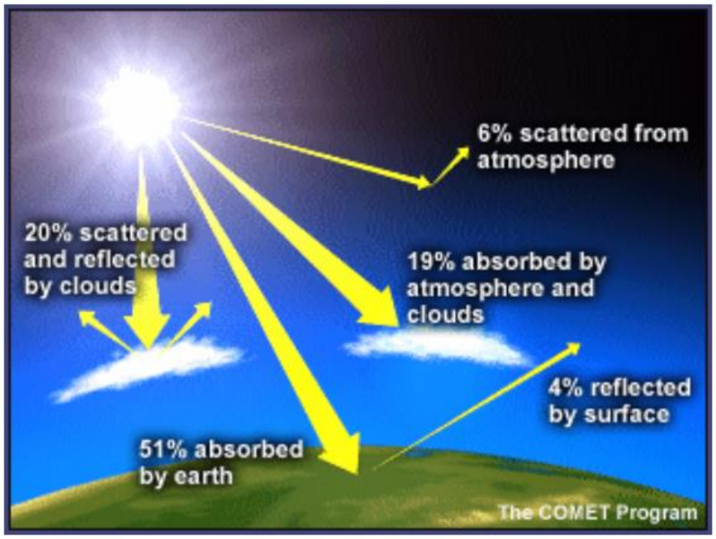
______________________________________________________________________

B. Where on the electromagnetic spectrum is our Sun's energy at the highest concentration?

______________________________________________________________________

______________________________________________________________________

5. Look at the next diagram which shows how the Sun's energy is either absorbed or reflected by various parts of our Earth system.




A. How much of our Sun's energy makes it all the way through the atmosphere to the surface of the Earth?

______________________________________________________________________

______________________________________________________________________

B. How much of our Sun's energy is absorbed by the surface of the Earth?

______________________________________________________________________

______________________________________________________________________

C. Once the energy has been absorbed it is re-radiated from the Earth as what kind of energy?

______________________________________________________________________

______________________________________________________________________

D. Why does the Earth get warm during the day but lose all its heat at night?

______________________________________________________________________

______________________________________________________________________

*Part E*

**Procedure**

Go to https://www.epa.gov/ghgemissions/overview-greenhouse-gases then answer the questions that follow.

**Analysis**

1. Where do greenhouse gases come from?

| Name | Where it comes from? |
|---|---|
| Carbon dioxide ($CO_2$) | |
| Water vapor ($H_2O$) | |
| Methane ($CH_4$) | |
| Nitrous oxides (NO, $NO_2$) | |
| Ozone ($O_3$) | |
| Chlorofluorocarbons (CFCs) | |

*Part F*

**Procedure**

Go to https://19january2017snapshot.epa.gov/climatechange_.html then answer the questions that follow.

**Analysis**

1. Why is the climate changing?

_______________________________________________

_______________________________________________

2. How is the climate changing?

_______________________________________________

_______________________________________________

3. What can we do about this change?

_______________________________________________

_______________________________________________

**Video Quiz**

TedED

*Climate Change: Earth's Giant Game of Tetris*

**Multiple Choice**

1. _____ How does the greenhouse effect influence the climate on Earth?
   A. It prevents Earth from getting too cold.
   B. It prevents Earth from getting too hot.
   C. It traps heat from the Sun.
   D. Both A and C.

2. _____ How much has $CO_2$ increased in the atmosphere since 1750?
   A. 15%
   B. 20%
   C. 40%
   D. 65%

3. _____ Which of the following energy sources uses fossil fuels?
   A. Nuclear plants
   B. Coal plants
   C. Solar panels
   D. Wind turbines

4. _____ What role does the ocean play in the carbon cycle?
   A. It releases $CO_2$ into the air.
   B. It absorbs $CO_2$ from the air.
   C. Neither A or B.
   D. Both A or B.

**Free Response**

5. How are fossil fuels used today?
   ______________________________________________________________________________
   ______________________________________________________________________________

6. How have humans altered the carbon cycle?
   ______________________________________________________________________________
   ______________________________________________________________________________

7. What are some of the effects of climate change?
   ______________________________________________________________________________
   ______________________________________________________________________________

**Presentation**

*A Closer Look at Solar Energy*

**Question**

How can we evaluate a solution to a complex real world problem?

**Procedure**

In teams, you will be exploring one of six solar energy criteria and trade-offs (compromises) that account for a range of constraints including: cost, aesthetics, reliability, social, cultural, or environmental impacts. Please type your answers to the following questions in a word document. Summarize your findings on a piece of butcher paper or other medium. Be prepared to present this information next class.

**Analysis**

1. Define your assigned constraint.
2. Describe three trade-offs.
3. Give a real-world example.
4. When thinking of your assigned criteria, how does it compare to using fossil fuels?
5. Did your team's thinking about solar energy change? Why or why not?

**Thinking Critically**
National Geographic Society
*Solar Energy*

**Question**
How can we learn more about the fundamentals of solar energy?

**Procedure**
Go to https://www.nationalgeographic.org/encyclopedia/solar-energy/. Watch the video Solar-Powered Water Heaters (scroll to the bottom of the page to find video) and then read the article on solar energy. Answer the questions that follow.

**Analysis**
*Matching*

1. _____ Climate
2. _____ Photovoltaic
3. _____ Electrodes
4. _____ Ultraviolet radiation
5. _____ Power grid
6. _____ Greenhouse effect
7. _____ Current
8. _____ Concentrated solar energy
9. _____ Convection
10. _____ Fossil fuel
11. _____ Semiconductor
12. _____ Infrared radiation
13. _____ Conduction
14. _____ Radiation

A. Coal, oil, or natural gas.
B. Part of the electromagnetic spectrum with wavelengths longer than visible light but shorter than microwaves.
C. Material that conducts electricity, but more slowly than a true conductor.
D. Able to convert solar radiation to electrical energy.
E. All weather conditions for a given location over a period of time.
F. Phenomenon where gases allow sunlight to enter Earth's atmosphere but make it difficult for heat to escape.
G. Conductor through which an electric current enters or leaves a substance (or a vacuum) whose electrical characteristics are being measured.
H. The process by which heat energy is transmitted through collisions between neighboring atoms or molecules.
I. Network of cables or other devices through which electricity is delivered to consumers.
J. Process of using mirrors to focus a large area of sunlight into a smaller area.
K. Transfer of heat by the movement of the heated parts of a liquid or gas.
L. The emission or transmission of energy in the form of waves or particles.
M. Steady, predictable flow of fluid within a larger body of that fluid.
N. Powerful light waves that are too short for humans to see, but can penetrate Earth's atmosphere.

*Free Response*

15. How are fossil fuels made? Are they renewable or nonrenewable? What impact do their uses have on the planet?

______________________________________________________________________

______________________________________________________________________

16. What is the difference between active and passive solar energy?

______________________________________________________________________

______________________________________________________________________

17. Describe two ways homeowners could incorporate passive solar energy into their homes.

______________________________________________________________________

______________________________________________________________________

18. What impact does solar energy have on society and the environment? Name three advantages and three disadvantages of using solar energy.

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

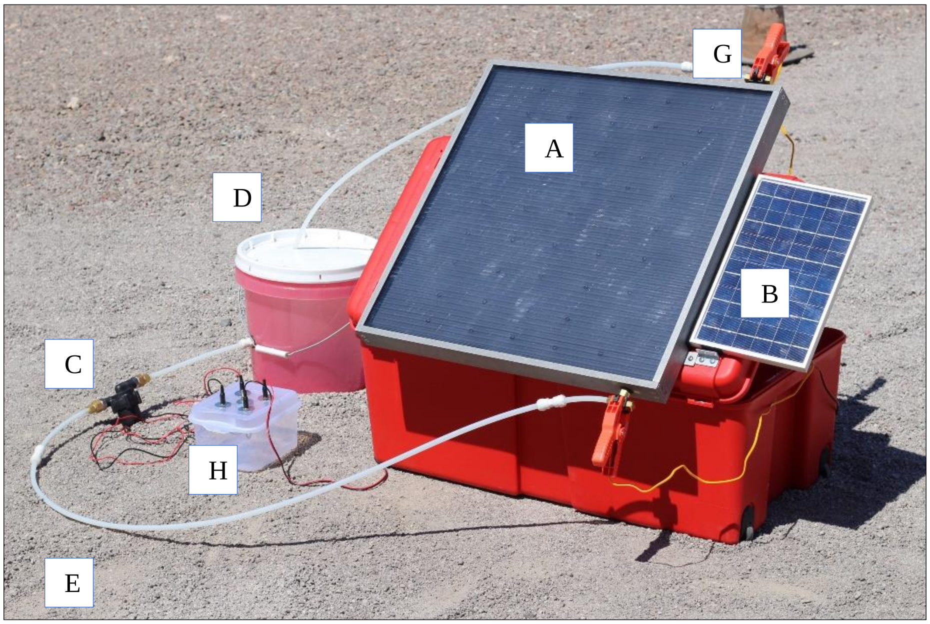
**Activity**

*Solar Thermal Water Heater*

**Question**

How can we build a solar thermal water heater?

**Materials**




A. Solar thermal collector, 1
B. 10 watt solar panel, 1
C. DC pump, 1
D. 3.5 gallon bucket, 1
E. Tubing, 2
F. Dual temperature meter, 1 (Not shown)
G. Type K thermocouples, 2
H. Switched electrical circuit, 1
I. Volumetric container, 1 (Not shown)
J. Tubing removal tool, 1 (Not show)

**Procedure**

*Solar Thermal Water Heating System Assembly*

1. Prop up the lid of the container using the wooden dowel inside. One side is cut at an angle. This should be on the back of the lid and the flat side should be at the bottom of the container. Remove the switch box out of the container.
2. Mount the PV panel with the Velcro onto the side of the thermal collector. (Figure 1)
3. Find and examine the pump. On the pump, there are arrows indicating the direction of flow. Attach the pump, on the IN ARROW SIDE, to the bucket by pushing the hose into the white quick connect attached to the side of the bucket. Push with much force with one hand on the pump while the other hand is inside the bucket for stability. To ensure the hose is secure, pull back on the hose with a slight tug, it should not detach. It is very

*Figure 1*

important to make sure no debris enters the hose, bucket, or the pump itself.

4. Taking care not to allow debris in either end of the hose, connect one of the hoses (tubing) to the pump on the OUT ARROW SIDE. Again, push with enough force to ensure the hose is completely within the housing assembly. (Figure 2)
5. Hold the hose attached to the pump above the bucket and fill the bucket with water. (Purified water is preferred, but not required). Place the lid on the bucket.

*Figure 2*

6. Set the bucket next to the wheeled container. Allow the hose to become parallel to the ground until water comes out of the hose. Be careful not to spill water on the electrical parts. Once water is seen, plug hose into the bottom port (inlet) of the solar collector. You have now primed and connected the pump. (Figure 3)

*Figure 3*

7. Taking care not allow debris to enter either end of the hose connect the second hose to the TOP port of the solar collector. The top port is the outlet of the solar collector. Again, use some force to fully connect the hose to the housing. The other end of the hose is placed inside the hole on the top side of the bucket lid or just placed into the bucket if there is no lid.

*Connecting the Switched Electrical Circuit*

1. Looking at the switched electrical circuit, ensure that the switch is in the OFF (down) position. (Figure 4)
2. At the switched electrical circuit, notice that there are two sets of female connectors: one to the right and one to the left of the switch. Of these, each set has a top connector indicated by red (positive), and a bottom connector indicated by black (negative). (Figure 5)

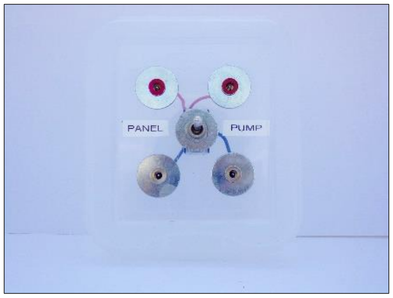



*Figure 4*

3. The PV panel has two male connectors. Notice that one wire is indicated by black (negative) and one is indicated by red (positive). The pump also hosts a wire with two male connectors, the positive is indicated by red, negative indicated by black.

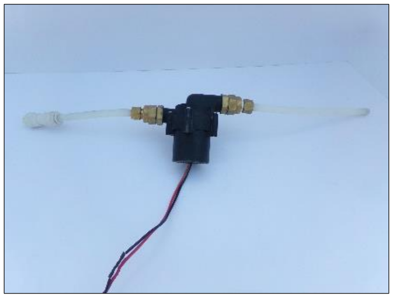


*Figure 5*

4. Looking again at the switched electrical circuit, the set of connectors to the left of the switch is the DC power side, meaning the LEFT SIDE is designed for the connection of the PV PANEL. Looking at this set of connectors to the left of the switch, one is indicated with red, and one is indicated with silver. Connect the RED wire from the PV panel to the RED connector on the LEFT side

of the switch. Connect the BLACK wire from the solar panel to the SILVER connector on the LEFT side of the switch.

5. Continuing to look at the switched electrical circuit, the set of connectors to the right of the switch is the Accessory side, meaning that the RIGHT SIDE is designed for the connection of the load. The load, in this case, is the PUMP. Looking at this set of connectors to the right of the switch, one is indicated with red, and one is indicated with silver. Connect the RED wire from the pump to the RED connector on the RIGHT side of the switch. Connect the BLACK wire from the pump to the SILVER connector on the RIGHT side of the switch. (Figure 6)
6. Flip the switch to the ON (up) position. Note that there are two off positions (down and middle), and one on or up position. Ensure that the switch is in the up position for operation.
7. Check to make sure that the pump is on and water is flowing. The outlet tube can be pulled from the bucket to see if there is flow. If water is not flowing, turn off the pump so that it is not damaged. If water is not flowing, check to see that the PV panel is receiving direct sunlight and that it is connected to the switched electrical circuit. Test again by turning on the pump. If water is not flowing, prime the pump again.
8. Flip the switch back to the OFF position until you are ready to measure the system.

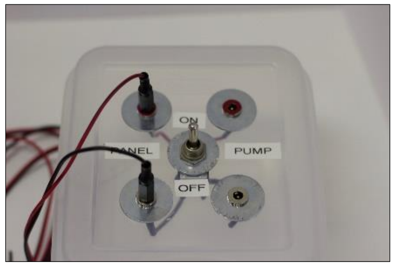


*Figure 6*

*Taking Measurements with Thermocouples*

1. Look at the yellow end of the thermocouples (part G). These prongs are different sizes and can only connect to the meter in one direction.
2. Look at the top of the dual temperature meter. There are two sets of female connection ports. One set is identified as T1, and the other by T2. Both T1 and T2 host a positive (+) and a negative (-) connection port. Locate them.
3. Take one of the clamp style thermocouples. This thermocouple will measure the inlet temperature at T1. Using the T1 connection ports on the dual temperature meter, connect the positive (+) prong on the yellow end of this thermocouple to the positive (+) connection port, and the negative (-) prong on the thermocouple to the negative (-) connection port. Clamp this thermocouple to the brass adapter at the inlet of the solar collector. The inlet is located on the bottom side of the solar collector.


*Figure 7*

4. Take the other clamp style thermocouple. This thermocouple will measure the outlet temperature at T2. Using the T2 connection ports on the dual temperature meter, connect the positive (+) prong on the yellow end of this thermocouple to the positive (+) connection port, and the negative (-) prong on the thermocouple to the negative (-) connection port. Clamp this thermocouple to the brass adapter at the outlet of the solar collector. The outlet is located on the top side of the solar collector.
5. Turn the dual temperature meter on. T1 and T2 are both shown in the digital screen. When the system is first powered on and water is flowing, the T1 and T2 temperature readings may vary within 0.2 degrees. This is a normal error for this temperature meter.
6. Power the system ON by flipping the switch on the switched electrical circuit. Note the time the system is powered on, as well as the temperatures at T1 and T2. These are the initial temperature measurements.
7. As the system runs, record T1 and T2 at periodic time intervals from zero (initial temperature) to 15 minutes. Record your results in Data Table I.

*Figure 8*

*Figure 9*

*Data Table I*

| | |
|---|---|
| **Initial temperature** | |
| **Final temperature** | |

| **Interval** | | **Time (min)** | **T1 (Inlet)** | **T2 (Outlet)** |
|---|---|---|---|---|
| 1 | 3 min | | | |
| 2 | 6 min | | | |
| 3 | 9 min | | | |
| 4 | 12 min | | | |

| | |
|---|---|
| *Flow rate: 1 L/(          )s* | *1 Liter/s = 0.001m$^3$/sec = 15.9 gal/min* |

*Measuring Flow Rate and Flow Rate Conversions*

1. Locate the volumetric container.
2. While the system is running, remove the lid to the water container so that the end of the outlet hose can be manipulated. Keep the water flow into the bucket.
3. Simultaneously, place the hose into the volumetric container and start the timer.
4. Stop the timer as soon as the container becomes full.
5. Note the volume of the container, as well as the time, in seconds, it took to fill the container. Flow rate is volume per unit time.
6. Discard the water from the volumetric container back into the bucket.
7. Replace the lid.
8. Record the flow rate in Data Table I then convert the flow rate to gal/min as shown below.

Convert to L/s (Insert calculate time in the parenthesis): $\frac{1\ Liter}{(\quad)s}$ = __________ L/s

Convert to $m^3$/s (Insert value above): (        ) L/s * $\frac{0.001\frac{m^3}{s}}{1\frac{L}{s}}$ = __________ $m^3$/s

Convert to gal/min (Insert L/s value above): (        ) L/s * $\frac{15.9\frac{gal}{min}}{1\frac{L}{s}}$ = __________ gal/min

*Disassembling the System*

1. Unclamp the thermocouples from the system, and disconnect each clamp from the dual temperature meter.
2. Flip the switch on the switched electrical circuit to the OFF (down) position. The water will cease to flow.
3. Disconnect the wires connecting the pump to the switched electrical circuit.
4. Disconnect the wires connecting the solar panel to the switched electrical circuit.
5. Using the hose removal tool (U-shaped), disconnect the hose from the outlet of the solar collector. The outlet is located on the top side of the solar collector. The hose removal tool is used by pressing the open side against the hose connector with some force, while pulling the hose out of the connection assembly. Once the hose is free from the outlet, remove this hose from the top of the bucket. Taking caution to avoid allowing debris to enter either end of the hose, drain any water from the hose and set it aside.
6. Using the tube hose removal tool, disconnect the hose from the inlet of the solar collector. The inlet is located on the bottom side of the solar collector.
7. Holding the hose and the pump wire away from the ground, empty the bucket.
8. Once the bucket is empty, use the hose removal tool to remove the hose from the pump, and the pump from the tube assembly connected to the bucket. Again, take care to avoid allowing debris to enter either the hose or the pump.

**Analysis**

As you operate the solar thermal collector compare what you see with the manufacturer's data sheet (Appendix A) describing it. Note the material types and the placement of these materials. Study the design and identify how is the Sun's energy is transferred.

1. Where do you observe radiant energy transfer?
   ______________________________________________________________________
   ______________________________________________________________________
2. Where do you observe convective energy transfer (is greenhouse effect being used here?)?
   ______________________________________________________________________
   ______________________________________________________________________
3. Where do you observe conductive energy transfer?
   ______________________________________________________________________
   ______________________________________________________________________

4. Are the type of materials and their placement ideal for the function?
______________________________________________________________________

______________________________________________________________________

5. Can you develop a better design?  What would you do?
______________________________________________________________________

______________________________________________________________________

**Going Further**

6. Create a graph (Temperature versus Time).  Use the data collected for T2.  Also add points indicating the initial and final temperatures of the water.  Note the unit used for temperature measurement on the y-axis.

**Thinking Critically**
*Material Properties*

**Question**
How can we evaluate the properties of different materials?

**Background**
When considering your materials to produce a new "solar thermal collector" you need to consider material properties like cost, color, and composition. Data Table I is a breakdown of the available materials, costs, and quantities. While looking at the data table think about:

1. How much does the material cost? Some materials may be cheap but ineffective for the applied purpose while others may be far too expensive to consider using.
2. What color do you want each part to be? Some colors or surface properties (shiny or dull) will react differently to light.
3. What is each material made of? Plastics and woods are composed of mostly carbon which would be considered a nonmetal (or an insulator). While all metals are conductors some metals like sodium are too reactive to use. The most highly conductive metals can be found in a single column in the periodic table. Semi-conductors also have their important applications (photovoltaic panels).

*Data Table I*

| Item | Cost ($) | Size/length/number |
|---|---|---|
| Foil | 10 | 6" x 6" |
| Black tubing | 30 | 3' |
| White tubing | 15 | 3' |
| Copper tubing | 100 | 3' |
| Zip ties | 5 | 5 |
| Trash bag (white) | 10 | 1 |
| Trash bag (black) | 20 | 1 |
| Plastic wrap | 5 | 6" x 6" |

**Materials**

- Periodic table

**Analysis**

1. While looking at a periodic table, identify which elements are the best conductors? Rank these conductors from the most to least expensive.

   ______________________________________________

   ______________________________________________

2. Which colors reflect light best?

   ______________________________________________

   ______________________________________________

3. Which colors absorb light best?

   ______________________________________________

   ______________________________________________

4. Would paint types (flat, semi-gloss or high-gloss) affect how light could be reflected or absorbed?
   ________________________________________________________________________________

   ________________________________________________________________________________

5. Are there any materials that may have the ability to reflect or absorb light without considering color?
   ________________________________________________________________________________

   ________________________________________________________________________________

6. If you use tubing to build your solar thermal collector, what color would you want it to be? What would you want it to be made of? How much would it cost? Are there tradeoffs to be considered?
   ________________________________________________________________________________

   ________________________________________________________________________________

7. Could you apply some of the materials to create a greenhouse effect? Would it make a difference in your desired results? Would it be cost effective?
   ________________________________________________________________________________

   ________________________________________________________________________________

**Teacher Version**

*Identifying Criteria and Constraints*

**Question**

How can students better understand how to identify criteria and constraints?

**Background**

When applying the principles of engineering design, you need to consider three major concepts: the problem, criteria, and constraints. A good activity to introduce these concepts involves asking students to design and safely build a stable structure to hold up a ping-pong ball, as high as possible, while using the fewest number of materials. Write this problem on the board. Next, ask students to identify the criteria. A **criterion** is a standard that can be measured. In this problem, examples of criteria include safety, number of materials, and height. Ask students to come up to the board and circle these criteria. Now, **constraints** are factors that limit your criteria. Time and materials are great examples of constraints. Ask students to come up to the board and write these constraints. If students are still unsure how to identity criteria and constraints go through the following examples before moving to the activity.

1. Your team is in the running to create a safe to assemble primary wastewater treatment device for the water district. This device must process water contaminated with soap, corn oil, coffee grounds, fertilizer, water, and vinegar. The team who filters out the most contaminates while neutralizing the pH and using the least amount of money to build their device will be awarded the contract.
2. You are competing to build a low-cost, natural looking dam that holds back 3 liters of water for 20 seconds. Your design must include a controlled way to release the water, and feature a method to get one fish across. This method needs to align with the natural movement of a fish.

**Materials**

- Ping-pong ball, 1
- Raw spaghetti noodles, 12
- Copy paper, 2
- Masking tape, 25 cm, 1

**Procedure**

1. Divide students into small groups (4-6).
2. Supply each group with the materials.
3. Ask students to construct a structure to hold up the ping-pong ball. The tallest structure wins.
4. Allow for a ten-minute planning session, followed by a ten-minute construction period.
5. After the construction phase have the students peer-review for the various methods and judge the winning structure.

**Activity**

*Designing a Solar Thermal Collector*

**Question**

How can we use the engineering design process to design a solar thermal collector?

**Procedure**

Your team's thermal collector was destroyed in a windstorm. Using the materials below, create a low-cost replacement. Consider the percentage of conductive and insulative materials. You have 2 class periods.

**Materials**

- Blue painters tape
- Peg board
- Scissors

*Data Table II*

| Item | Cost ($) | Size/length/number |
|---|---|---|
| Foil | 10 | 6" x 6" |
| Black tubing | 30 | 3' |
| White tubing | 15 | 3' |
| Copper tubing | 100 | 3' |
| Zip ties | 5 | 5 |
| Trash bag (white) | 10 | 1 |
| Trash bag (black) | 20 | 1 |
| Plastic wrap | 5 | 6" x 6" |

1. Restate the problem your team is trying to solve. List the possible criteria (3) and constraints.
   A. Problem

   ______________________________________________

   ______________________________________________

   B. Criteria (Measureable)
      a. ______________________________________________
      b. ______________________________________________
      c. ______________________________________________

   C. Constraints (Limitations)

   ______________________________________________

   ______________________________________________

2. Develop a solution to the problem. Use Data Table III to help you create a drawing, list of instructions, and supplies.

*Data Table III: Individual Solution*

| **Drawing** |
| --- |
| |
| **Instructions** |
| |

| **Materials** | | | |
| --- | --- | --- | --- |
| *Item* | *Cost ($)* | *Quantity* | *Subtotal* |
| Foil | 10 | | |
| Black tubing | 30 | | |
| White tubing | 15 | | |
| Copper tubing | 100 | | |
| Zip ties | 5 | | |
| Trash bag (white) | 10 | | |
| Trash bag (black) | 20 | | |
| Plastic wrap | 5 | | |
| | | **Total** | |

3. Create a criteria rubric.

*Criteria Rubric*

| **Weights** | | *3 points* | *2 points* | *1 point* |
|---|---|---|---|---|
| **Categories** | | | | |
| | | | | |
| | | | | |

4. With the help of your criteria rubric, fill in the evaluation matrix as you consider each member's solution. Circle the winning design.

*Evaluation Matrix*

| **Categories** | | | | | *Total* |
|---|---|---|---|---|---|
| Weights | | | | | |
| **Solutions** | **1** | | | | |
| | **2** | | | | |
| | **3** | | | | |
| | **4** | | | | |
| | **5** | | | | |
| | **6** | | | | |

5. After selecting a solution to the problem, help your team build a device. Use Data Table IV to keep track of the supplies your team uses plus costs.
6. Once the device is built take it outside then test temperature and flow rate. Record your results in Data Table V.
7. Optimize your solution! Use Data Table IV to keep track of the materials you use plus costs.

*Data Table IV: Team Solution*

| Item | Cost ($) | Size/length/number | Subtotal | Optimization |
|---|---|---|---|---|
| Foil | 10 | 6” x 6” | | |
| Black tubing | 30 | 3’ | | |
| White tubing | 15 | 3’ | | |
| Copper tubing | 100 | 3’ | | |
| Zip ties | 5 | 5 | | |
| Trash bag (white) | 10 | 1 | | |
| Trash bag (black) | 20 | 1 | | |
| Plastic wrap | 5 | 6” x 6” | | |
| | | *Total* | | |

*Data Table V*

| | |
|---|---|
| **Initial temperature** | |
| **Final temperature** | |

| **Interval** | | **Time** | **T1 (Inlet)** | **T2 (Outlet)** |
|---|---|---|---|---|
| 1 | 3 min. | | | |
| 2 | 6 min. | | | |
| 3 | 9 min. | | | |
| 4 | 12 min. | | | |

| | |
|---|---|
| *Flow rate: 1 L/(            )s* | *1 Liter/s = 0.001m$^3$/sec = 15.9 gal/min* |

**Analysis**

1. Describe how the solar thermal water heater works.

______________________________________________

______________________________________________

______________________________________________

______________________________________________

2. Distinguish between the role of the photovoltaic panel and the thermal panel. How do they use the energy from the Sun differently?

______________________________________________

______________________________________________

3. What materials were the best conductors? Insulators?

______________________________________________

______________________________________________

4. How does the speed of water flow affect temperature?

_______________________________________________________________________________

_______________________________________________________________________________

5. How effective was your team's initial solution? What did your team do to optimize its solution?

_______________________________________________________________________________

_______________________________________________________________________________

_______________________________________________________________________________

_______________________________________________________________________________

**Assessment**

*Solar Energy*

**Free Response**

Answer the following questions on a separate piece of paper.

1. What is the greenhouse effect? Name four major greenhouse gases. How do they work to absorb infrared radiation?
2. How and why is the climate changing? What can we do about this change?
3. What impact does solar energy have on society and the environment? Name three advantages and three disadvantages of using solar energy.
4. In the engineering design challenge, what problem was your team trying to solve? What were the criteria and constraints? How effective was your team's initial solution? What did your team do to optimize the solution?

**Answer Key**
*Web Quest: Greenhouse Effect*

*Part A*
**Analysis**
1. What is the origin of the term "greenhouse effect"? Greenhouse effect refers to conditions where a given zone will have higher temperatures because of reflected radiant energy.
2. How does a real greenhouse stay warm even with snow outside? Radiant energy is reflected and "trapped" in a given area. In a greenhouse energy from the sun enters the transparent structure and then reflected from the ground and then reflected back again upon reaching the inner side of the transparent structure, thus becoming trapped inside. This causes an increased amount of radiant energy inside causing increased temperatures.
3. What difference does a jungle make? More plants will reduce $CO_2$ gas which is one of the leading greenhouse gases. Less Jungle or plant mean higher levels of $CO_2$ and a greater greenhouse effect.
4. What difference does an ocean make? Oceans tend to absorb a lot of excess $CO_2$ which has an acidic effect on the water causing negative effects on the sea environment.
5. What is a cloud? Clouds are zones of gases (mostly water vapor) that will cause a greenhouse effect reflecting light.
6. What type of effects do clouds have on the temperature of the Earth? Clouds can affect the temperature of the Earth in two ways. First they can act as a filter and reflect radiant energy back into space, which causes cooler temperatures. Second they can have a "greenhouse effect" and reflect radiant energy back toward the Earth causing warmer temperatures.
7. Does the height of the clouds make a difference? High altitude clouds are those that tend to act as filters: while lower altitude (and thicker) clouds tend to produce the greenhouse effect.

*Part B*
**Analysis**
1. What are the four major greenhouse gases and their formulas? Carbon dioxide ($CO_2$), Water vapor ($H_2O$), Methane (CH4), and Nitrous oxides (NO & $NO_2$). Answers may also include ozone ($O_3$), and Chlorofluorocarbons (CFC's).
2. What other factors influence the greenhouse effect? Background conditions (temperature of the atmosphere as well as the Earth's surface.

*Part C*
**Analysis**
1. What does albedo mean? Albedo is a measure of how reflective the surface of the Earth is. An example is snow will reflect more than grass.
2. How does the type of Earth surface change the albedo? It will determine how much sun light gets reflected from the surface of the Earth.

*Part D*
**Analysis**
1. How do carbon dioxide and other greenhouse gases work to absorb infrared radiation? They have complex 3D structures in their chemical bonds which allow for radiant energy to be absorbed, stored and then released back to the environment.
2. Why don't nitrogen gas ($N_2$) and oxygen ($O_2$) gas act as greenhouse gases? The bonds between two nitrogen atoms or two oxygen atoms geometrically simple to allow for the absorption storage and release of radiant energy.
3. Look at the graph about solar radiation. The x-axis of this graph contains the various sizes of radiation of the electromagnetic spectrum (X rays on the left have the smallest wavelength, while Radio waves on the right have the largest wavelength). The Y axis of this graph indicates increased concentration of these types

of radiation. What is the size range of a single wavelength of visible light? (nm means nanometer) Between 400 nm and 700 nm. What is the size range of a single wavelength of infrared light? Between 700 nm and 1 mm.

4. The yellow line on this graph indicates the types and concentrations of the radiation released by our Sun. What kinds of radiation does our Sun release? (Hint: Look at the diagram and list the energy types.) UV, visible, and infrared light. Where on the electromagnetic spectrum is our Sun's energy at the highest concentration? Visible light
5. Look at the next diagram which shows how the Sun's energy is either absorbed or reflected by various parts of our Earth system. How much of our Sun's energy makes it all the way through the atmosphere to the surface of the Earth? 55% How much of our Sun's energy is absorbed by the surface of the Earth? 51% Once the energy has been absorbed it is re-radiated from the Earth as what kind of energy? Radiant energy (mostly infrared) Why does the Earth get warm during the day but lose all its heat at night? The atmosphere and clouds help regulate the temperature by reflection.

*Part E*

**Analysis**

1. Where do greenhouse gases come from?

| Name | Where it comes from? |
|---|---|
| Carbon dioxide ($CO_2$) | Burning fossil fuels. |
| Water vapor ($H_2O$) | Evaporation of the water cycle. |
| Methane ($CH_4$) | The production and transport of coal, natural gas, and oil. Methane emissions also result from livestock and other agricultural practices and by the decay of organic waste in municipal solid waste landfills. (farts). |
| Nitrous oxides (NO, $NO_2$) | Agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste. |
| Ozone ($O_3$) | Operation of electric motors. |
| Chlorofluorocarbons (CFCs) | Burning fossil fuels and industrial processes. |

*Part F*

**Analysis**

1. Why is the climate changing? Over the past century, human activities have released large amounts of carbon dioxide and other greenhouse gases into the atmosphere. Most greenhouse gases come from burning fossil fuels to produce energy, although deforestation, industrial processes, and some agricultural practices also emit gases into the atmosphere.
2. How is the climate changing? Earth's average temperature has risen by 1.5°F over the past century, and is projected to rise another 0.5 to 8.6°F over the next hundred years. Small changes in the average temperature of the planet can translate to large and potentially dangerous shifts in climate and weather. Rising global temperatures have been accompanied by changes in weather and climate. Many places have seen changes in rainfall, resulting in more floods, droughts, or intense rain, as well as more frequent and severe heat waves.
3. What can we do about this change? You can take steps at home, on the road, and in your office to reduce greenhouse gas emissions and the risks associated with climate change. Many of these steps can save you money; some, such as walking or biking to work, can even improve your health! You can also get involved on a local or state level to support energy efficiency, clean energy programs, or other climate programs.

**Answer Key**

*Video Quiz: Climate Change-Earth's Giant Game of Tetris*

**Multiple Choice**

1. How does the greenhouse effect influence the climate on Earth? D
2. How much has $CO_2$ increased in the atmosphere since 1750? C
3. Which of the following energy sources uses fossil fuels? D
4. What role does the ocean play in the carbon cycle? D

**Free Response**

1. How are fossil fuels used today? Answers may vary; Transportation, heating.
2. How have humans altered the carbon cycle? Answers may vary; Excessive use is overloading the Earth system.
3. What are some of the effects of climate change? Answers may vary; Rising sea level, rise in global temperature.

**Answer Key**

*Thinking Critically: Solar Energy*

1. E
2. D
3. G
4. N
5. I
6. F
7. M
8. J
9. K
10. A
11. C
12. B
13. H
14. L
15. How are fossil fuels made? Are they renewable or nonrenewable? What impact do their uses have on the planet? Answers may vary; Photosynthesis is also responsible for all the fossil fuels on Earth. Scientists estimate that about 3 billion years ago, the first autotrophs evolved in aquatic settings. Sunlight allowed plant life to thrive and evolve. After the autotrophs died, they decomposed and shifted deeper into the Earth, sometimes thousands of meters. This process continued for millions of years. Under intense pressure and high temperatures, these remains became what we know as fossil fuels. Microorganisms became petroleum, natural gas, and coal. People have developed processes for extracting these fossil fuels and using them for energy. However, fossil fuels are a nonrenewable resource. They take millions of years to form.
16. What is the difference between active and passive solar energy? Answers may vary; Active solar energy is energy from the Sun that is increased using electricity or other mechanical equipment. Passive solar energy is power from the Sun that requires no other energy or mechanical system.
17. Describe two ways homeowners could incorporate passive solar energy into their homes. Answers may vary; Align the building with the Sun's daily path to receive desirable amounts of sunlight; cool roofs; radiant barriers, green roofs.
18. What impact does solar energy have on society and the environment? Name three advantages and three disadvantages of using solar energy. Answers may vary; Advantages: Renewable, clean, can be used with other renewable sources of energy; Disadvantages: Cost, heavy, sunlight variability (cloud cover).

**Answer Key**

*Activity: Solar Thermal Water Heater*

**Analysis**

1. Where do you observe radiant energy transfer? Solar panel.

2. Where do you observe convective energy transfer (is greenhouse effect being used here?)? Solar thermal collector.
3. Where do you observe conductive energy transfer? Inside the bucket.
4. Are the type of materials and their placement ideal for the function? Answers may vary.
5. Can you develop a better design? What would you do? Answers may vary.

**Answer Key**

*Thinking Critically: Material Properties*

1. While looking at a periodic table, identify which elements are the best conductors? Rank these conductors from the most to least expensive. Copper, Silver, Gold; Gold, Silver, Copper
2. Which colors reflect light best? White reflects all colors of light.
3. Which colors absorb light best? Black absorbs all colors of light.
4. Would paint types (flat, semi-gloss or high-gloss) affect how light could be reflected or absorbed? A flat paint would absorb best while a high gloss will reflect best (semi-gloss = semi effect).
5. Are there any materials that may have the ability to reflect or absorb light without considering color? A reflective surface like a mirror or reflective metal (polished stainless steel or aluminum foil) will work.
6. If you use tubing to build your solar thermal collector, what color would you want it to be? What would you want it to be made of? How much would it cost? Are there tradeoffs to be considered? Flat black; Copper; ¼ inch copper tubing is $22-$50 for a 50 foot coil; A 50 foot section of ¼ plastic drip tubing can be as low as $4.21; Copper tubing cost more but it is made of a conductor while the less expensive plastic tubing is made of an insulator. The plastic tubing is made of a black colored plastic while the copper tubing might need to be spray painted a flat black color.
7. Could you apply some of the materials to create a greenhouse effect? Would it make a difference in your desired results? Would it be cost effective? Based on the students design structure, they may choose to locate the fluid carrying tubes in a region where irradiation, convection and conduction would occur in the same place. This type of design may provide more efficient results.

**Answer Key**

*Activity: Designing a Solar Thermal Collector*

1. Restate the problem your team is trying to solve. Your team's thermal collector was destroyed in a windstorm. Using the materials below, create a low-cost replacement. Consider the percentage of conductive and insulative materials. List the possible criteria (3) and constraints. Criteria: Low-cost, conductive and insulative materials; Constraints: Time, materials.

*Sample: Criteria Rubric*

| **Weights** | | *3 points* | *2 points* | *1 point* |
|---|---|---|---|---|
| **Categories** | Low-cost | Description of what a score in this category looks like. | Description of what a score in this category looks like. | Description of what a score in this category looks like. |
| | % conductive materials | Description of what a score in this category looks like. | Description of what a score in this category looks like. | Description of what a score in this category looks like. |
| | % insulative materials | Description of what a score in this category looks like. | Description of what a score in this category looks like. | Description of what a score in this category looks like. |

*Sample: Evaluation Matrix*

| | **Categories** | *Low-cost* | *% conductive materials* | *% insulative materials* | *Total* |
|---|---|---|---|---|---|
| | Weights | 3 | 1 | 2 | |
| **Solutions** | **1** | 3 / 9 | 2 / 2 | 3 / 6 | 17 |
| | **2** | | | | |
| | **3** | | | | |
| | **4** | | | | |
| | **5** | | | | |
| | **6** | | | | |

**Analysis**

1. Describe how the solar thermal water heater works. Answers may vary; The solar panel powers a pump to move water from a bucket, through a thermal panel, then back to the bucket.
2. Distinguish between the role of the photovoltaic panel and the thermal panel. How do they use the energy from the Sun differently? Answers may vary; A photovoltaic panel allows photons to knock electrons free from atoms generating a flow of electricity. It transfers radiant energy to the thermal panel where water is heated via conduction (from black panel to copper tubing to water) and convection (air between the outer plastic panel and the black panel).
3. What materials were the best conductors? Insulators? Answers may vary.
4. How does the speed of water flow affect temperature? The slower the water flow greater the temperature.
5. How effective was your team's initial solution? What did your team do to optimize its solution? Answers may vary.

**Answer Key**

*Assessment: Solar Energy*

1. What is the greenhouse effect? Name four major greenhouse gases. How do they work to absorb infrared radiation? Answers may vary; Phenomenon where gases allow sunlight to enter Earth's atmosphere but make it difficult for heat to escape; Water vapor, carbon dioxide, methane, ozone, CFCs; They have complex 3D structures in their chemical bonds which allow for radiant energy to be absorbed, stored and then released back to the environment.
2. How and why is the climate changing? What can we do about this change? Answers may vary; Earth's average temperature has risen by 1.5°F over the past century, and is projected to rise another 0.5 to 8.6°F over the next hundred years. Small changes in the average temperature of the planet can translate to large and potentially dangerous shifts in climate and weather. Rising global temperatures have been accompanied by changes in weather and climate. Many places have seen changes in rainfall, resulting in more floods, droughts, or intense rain, as well as more frequent and severe heat waves. Over the past century, human activities have released large amounts of carbon dioxide and other greenhouse gases into the atmosphere. Most greenhouse gases come from burning fossil fuels to produce energy, although deforestation, industrial processes, and some agricultural practices also emit gases into the atmosphere. You can take steps at home, on the road, and in your office to reduce greenhouse gas emissions and the risks associated with climate change. Many of these steps can save you money; some, such as walking or biking to work, can even improve your health! You can also get involved on a local or state level to support energy efficiency, clean energy programs, or other climate programs.
3. What impact does solar energy have on society and the environment? Name three advantages and three disadvantages of using solar energy. Answers may vary; Advantages: Renewable, clean, can be used with other renewable sources of energy; Disadvantages: Cost, heavy, sunlight variability (cloud cover).

4. In the engineering design challenge, what problem was your team trying to solve? What were the criteria and constraints? How effective was your team's initial solution? What did your team do to optimize the solution? Answers may vary; Your team's thermal collector was destroyed in a windstorm. Using the materials below, create a low-cost replacement. Consider the percentage of conductive and insulative materials; Criteria: Low-cost, conductive and insulative materials; Constraints: Time, materials

*Grading Rubric*

| **Points** | | **1** | **2** | **3** |
|---|---|---|---|---|
| **Question 1** | *Vocabulary* | Used few vocabulary words from unit. | Mostly used vocabulary words from unit. | Excellent use of vocabulary from unit. |
| | *Completeness* | Did not answer all parts of the question. | Mostly answered all parts of the question. | Completely answered all parts of the question. |
| | *Accuracy* | Did not answer all parts of the question right. | Mostly answered all parts of the question right. | Accurately answered all parts of the question. |
| | | | **Total** | |

| **Points** | | **1** | **2** | **3** |
|---|---|---|---|---|
| **Question 2** | *Vocabulary* | Used few vocabulary words from unit. | Mostly used vocabulary words from unit. | Excellent use of vocabulary from unit. |
| | *Completeness* | Did not answer all parts of the question. | Mostly answered all parts of the question. | Completely answered all parts of the question. |
| | *Accuracy* | Did not answer all parts of the question right. | Mostly answered all parts of the question right. | Accurately answered all parts of the question. |
| | | | **Total** | |

| **Points** | | **1** | **2** | **3** |
|---|---|---|---|---|
| **Question 3** | *Vocabulary* | Used few vocabulary words from unit. | Mostly used vocabulary words from unit. | Excellent use of vocabulary from unit. |
| | *Completeness* | Did not answer all parts of the question. | Mostly answered all parts of the question. | Completely answered all parts of the question. |
| | *Accuracy* | Did not answer all parts of the question right. | Mostly answered all parts of the question right. | Accurately answered all parts of the question. |
| | | | **Total** | |

| **Points** | | **1** | **2** | **3** |
|---|---|---|---|---|
| **Question 4** | *Vocabulary* | Used few vocabulary words from unit. | Mostly used vocabulary words from unit. | Excellent use of vocabulary from unit. |
| | *Completeness* | Did not answer all parts of the question. | Mostly answered all parts of the question. | Completely answered all parts of the question. |
| | *Accuracy* | Did not answer all parts of the question right. | Mostly answered all parts of the question right. | Accurately answered all parts of the question. |
| | | | **Total** | |